

# Lunar Analog Feasibility Study Results

Ronita L. Cromwell, PhD  
PI and Flight Analogs Project Scientist

Joe Neigut  
Flight Analogs Project Manager

# Lunar Analog Feasibility Study (LAFS), Phase I

- Purpose:
  - To determine the feasibility of using a 9.5° head-up tilt bed rest model to simulate the effects of the 1/6 g load to the human body that exists on the lunar surface.
  - Development of such an analog will allow for future studies to examine the potential for a protective effect of partial gravity on the human body, and help to guide countermeasure development for this environment.

# Study Protocol

- Pre-bed rest
  - Subjects spent 3 days prior to bed rest eating a standardized diet and undergoing the following measures:
    - Plasma Volume



# Study Protocol

- During bed rest
  - Subjects spent 6 days in bed at  $9.5^\circ$  head-up tilt
    - 35% of the day was spent “standing”
    - 65% of the day was spent “sitting”
  - Subjects slept in the horizontal position



Standing



Sitting



# Study Protocol

- During bed rest
  - Jobst® thigh high compression stockings were worn by subjects.
    - Stockings facilitated the upward shift of body fluids that would be expected on the lunar surface and modeled changes to the cardiovascular system.
    - Stockings were “off the shelf” and sized small, medium and large. Stockings averaged ~18 mmHg of pressure.
  - Foot forces were monitored to insure a  $1/6^{\text{th}}$  body weight load during standing
  - Comfort was assessed using a visual analog scale



Thigh high compression stockings

# Study Protocol

- Post-bed rest
  - Subjects spent 2 days receiving reconditioning exercises while ambulatory
  - Plasma Volume was assessed on the evening prior to getting up from bed

# Subjects

- The initial phase of the study was conducted in collaboration with Dr. Peter Cavanagh while he was at Cleveland Clinic.
  - Of the initial 8 subjects:
    - 5 subjects (1 female, 4 males) were run at Cleveland Clinic
    - 3 subjects (2 females, 1 male) were run at the NASA Flight Analogs Research Unit at UTMB in Galveston, TX.
- Due to stocking-related discomfort experienced by these first 8 subjects, 10 more subjects (3 females, 7 males) were run to examine comfort using different styles of stockings.
  - Two of these subjects were dismissed. One was dismissed for inability to tolerate the stockings and the other for nerve compression at the toes that caused numbness.
- Data from these 8 remaining subjects are the focus of this LAFS phase 1 presentation.

# Stocking Styles

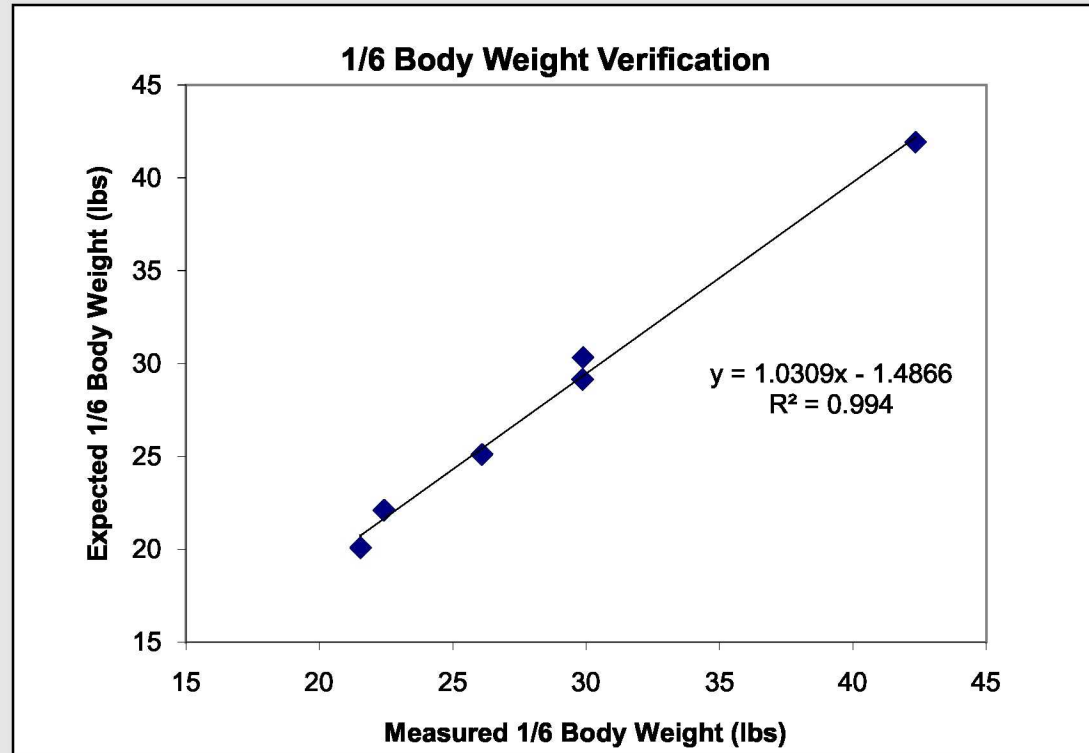
- Each stocking style maintained the ~18 mmHg average pressure and were custom fit for each subject.
  - Thigh high, closed toe (n=2)
  - Thigh high, open toe (n=3)
  - Knee high, open toe (n=3)

Thigh high,  
open toe



Knee high,  
open toe

# Force Verification

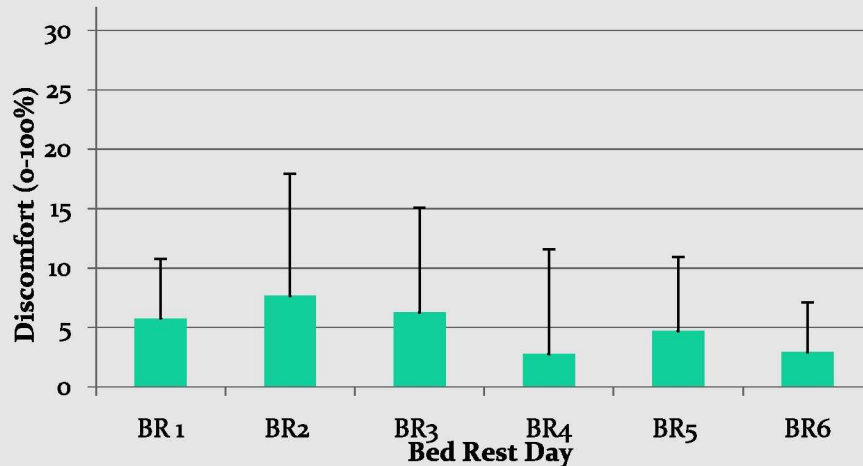


This figure depicts the 1/6 force verification during the standing position in the lunar analog bed. One sixth of the body weight as measured while “standing” in the bed (x axis) is plotted against the expected 1/6 body weight (y axis) for each subject. Regression analysis indicates 99.4% ( $r^2=0.994$ ) of the variation in the measured 1/6 body weight is explained by the relationship to the expected 1/6 body weight. In other words, the lunar analog bed accurately imparts a 1/6 load to the subject.



# Comfort Data

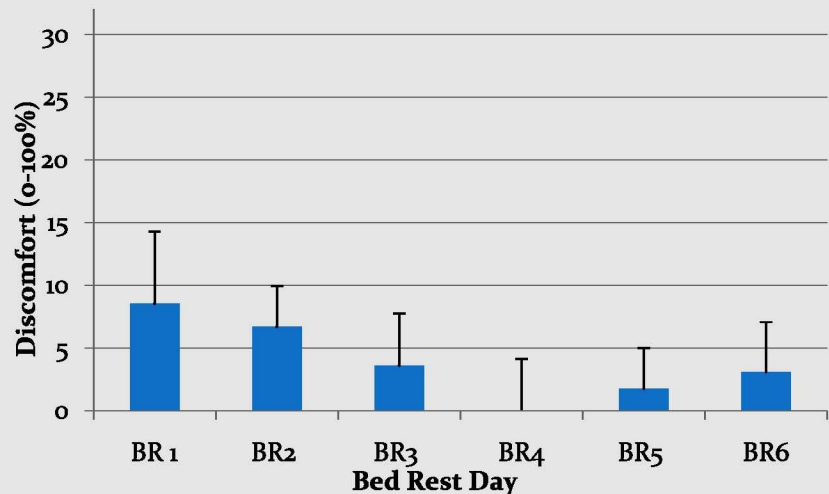
## Overall



Data depict more overall and lower back discomfort early in bed rest.

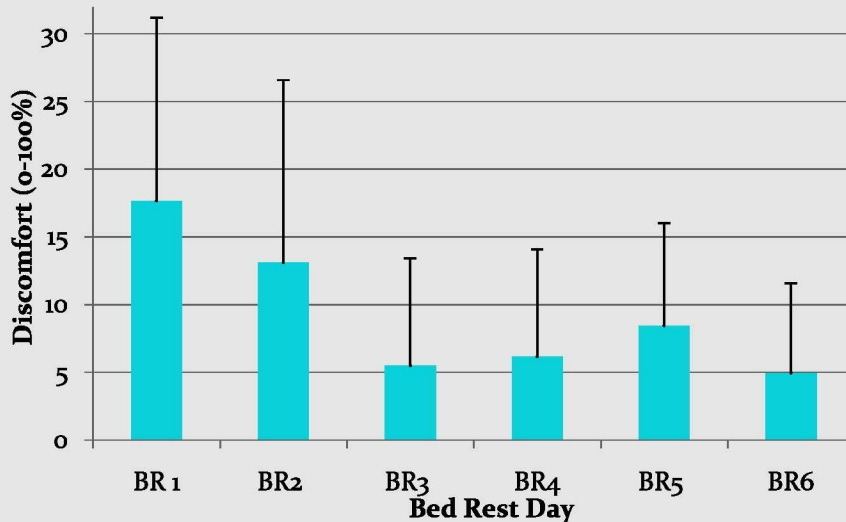
Data for Overall and Lower Back regions are plotted against bed rest days. Data represent means and standard deviations for each bed rest day. Discomfort is expressed as zero to 100%.

## Lower Back



# Comfort Data

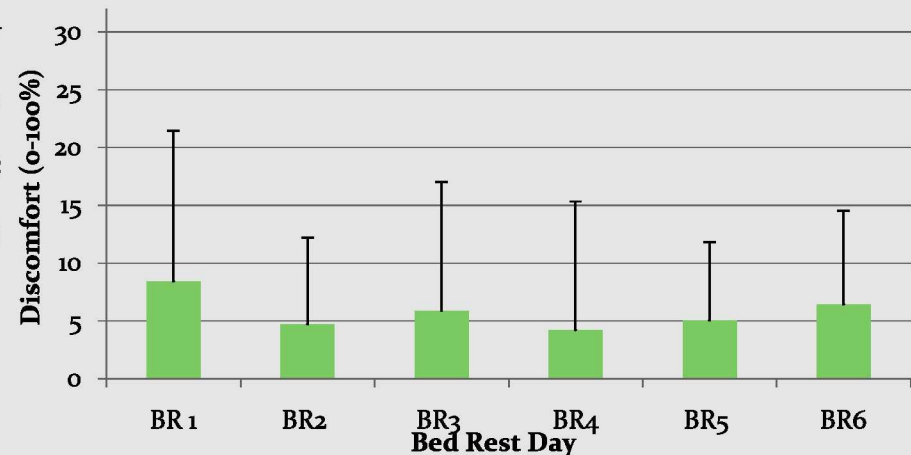
## Feet



Data for Feet and Knee regions are plotted against bed rest days. Data represent means and standard deviations for each bed rest day. Discomfort is expressed as zero to 100%.

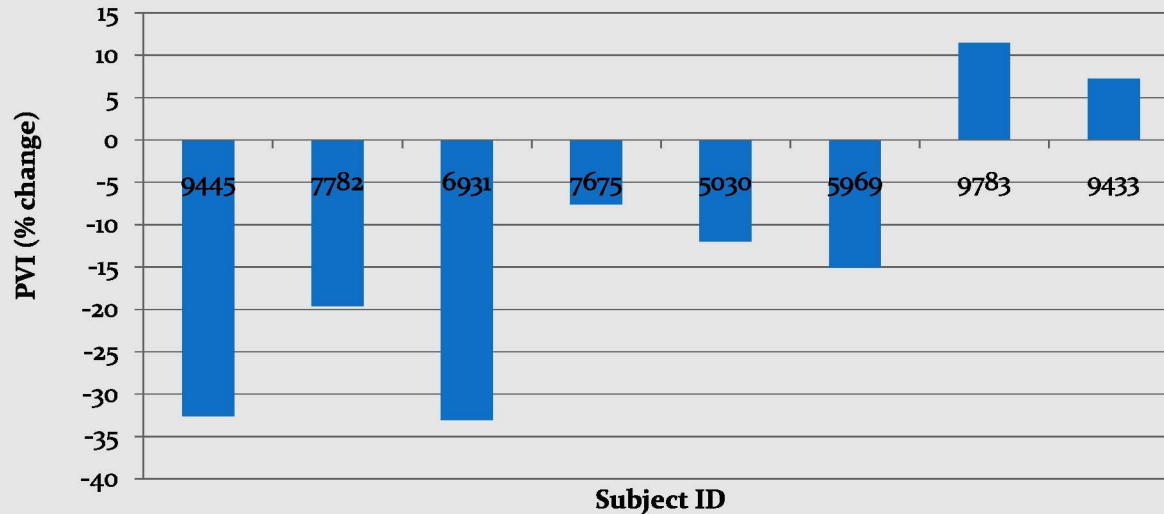
For the feet, the greatest discomfort was reported early in bed rest. Many of these complaints were related to pain near the toes in the open toe stockings. Knee discomfort was greatest on BR1.

## Knees



# Plasma Volume

## Plasma Volume Index



This figure depicts plasma volume index (PVI) plotted for each subject. Six subjects demonstrated the negative shift in PVI that would be expected in a lunar environment. Average PVI % change for these subjects was  $-12.7 \pm 15.3$ . This mean was greater than the  $-6\%$  change predicted by Digital Astronaut for the lunar surface. The large degree of variability in these data may be attributed to the short, 3-day pre-bed rest period for diet stabilization.

# LAFS, Phase II

- Purpose of phase II testing.
  - determine subject comfort and tolerance in the lunar gravity simulator bed
  - verify force measures to determine that  $1/6$ th body weight was obtained in the standing configuration of the bed
  - assess plasma volume changes

# LAFS Phase II

- Changes made in Phase II
  - 13-day diet stabilization in pre-bed rest
  - Fluid shift strategy
    - Lower compression stockings (average ~ 12 mm Hg)
    - Closed toe, knee high, Elvarex fabric (for comfort)
    - Modified Buerger-Allen exercises were used to facilitate upward shift of fluids. Buerger-Allen exercises are unweighted foot and ankle movements used clinically to improve circulation in patients with peripheral vascular disease.
- Dependent Measures
  - Comfort logs (visual analog scale)
  - Force verification in the standing position
  - Plasma volume



# Comfort Assessment

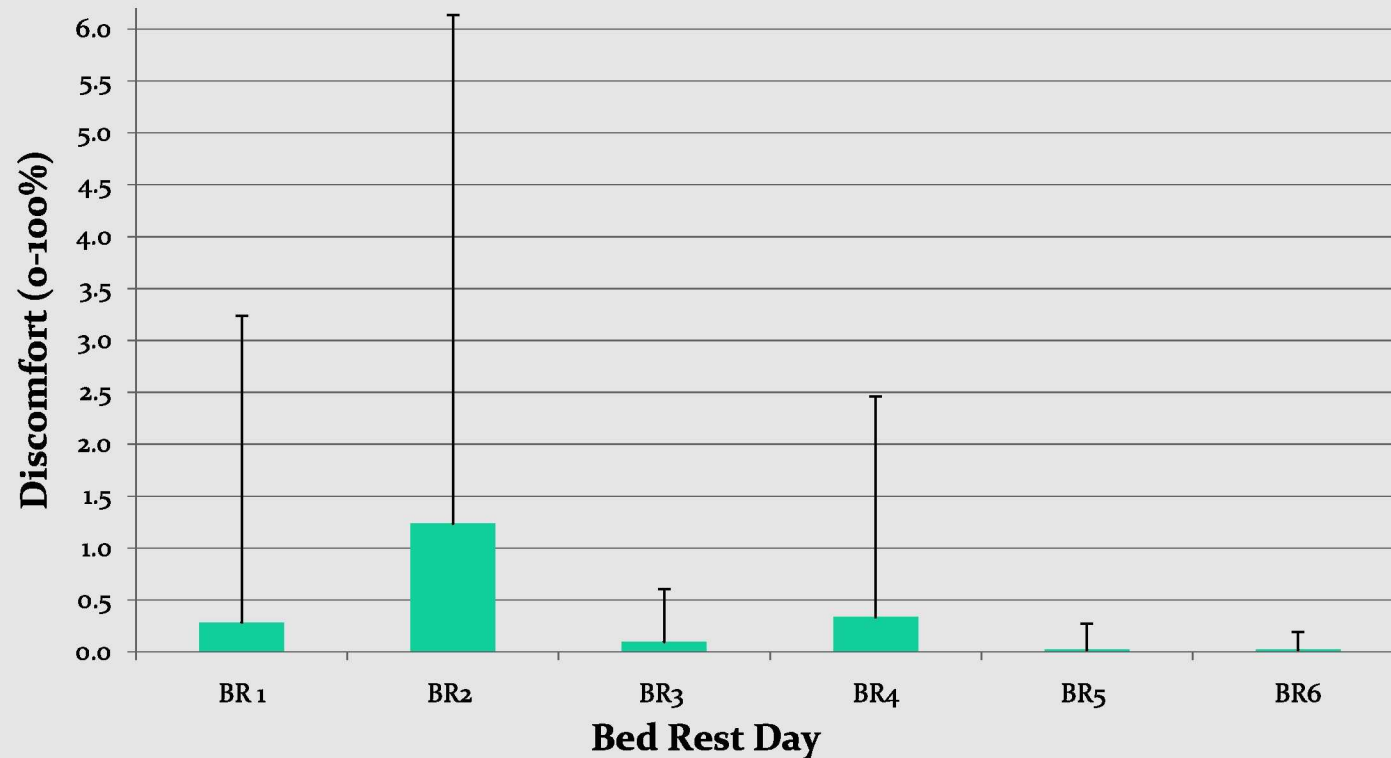
- Comfort Log
  - Comfort levels were assessed using a visual analog scale
  - Subjects marked their pain assessment on a range from 0 (no pain) to 10 (worst pain).
  - Scales were measured in millimeters and provided measures from 0 to 100.



# Comfort Results

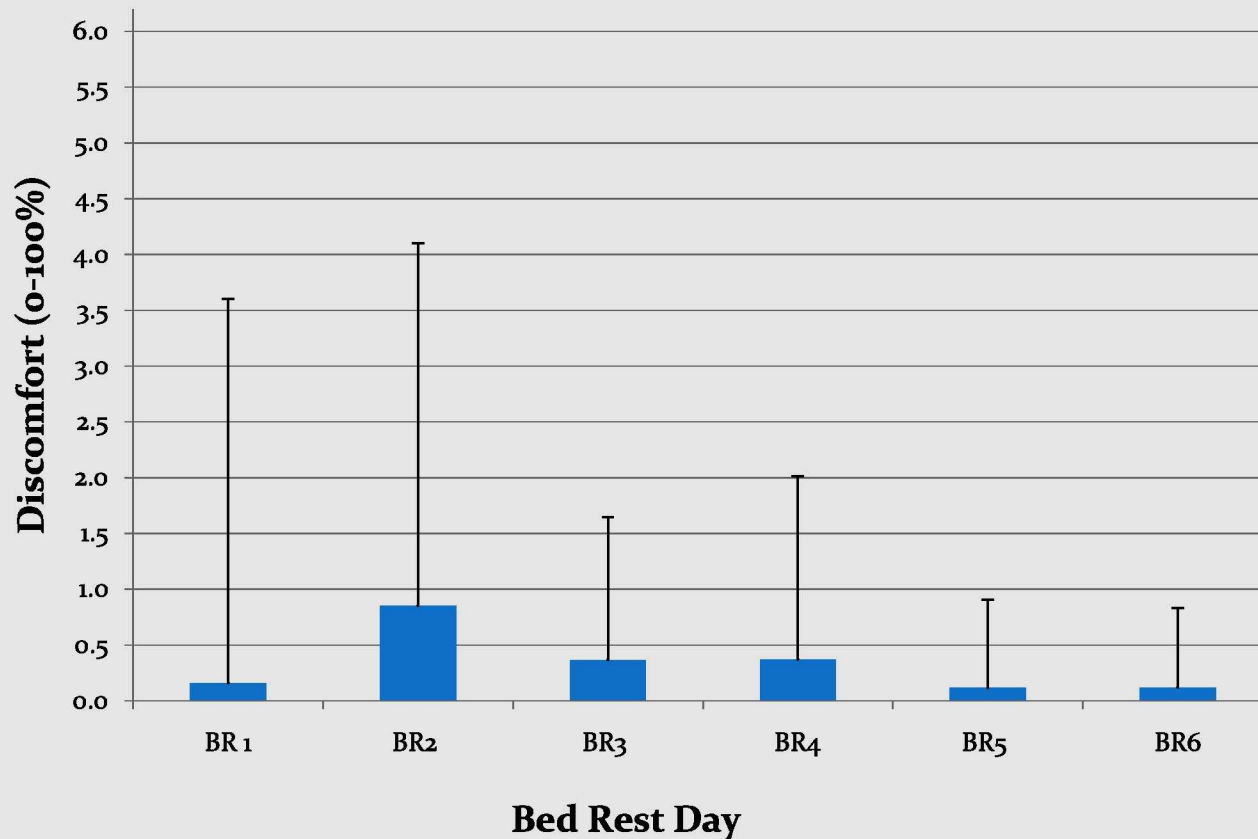
- Subjects experienced very little pain and consistently reported zeros and low values for their pain ratings.
- Because of the large number of zeros in the data set, use of inferential statistics was not possible.
- Descriptive analyses were completed.
- Graphs on subsequent slides represent means and standard deviations for each day of bed rest.
- Note that discomfort is expressed as a rating from zero to 100%.

## Overall



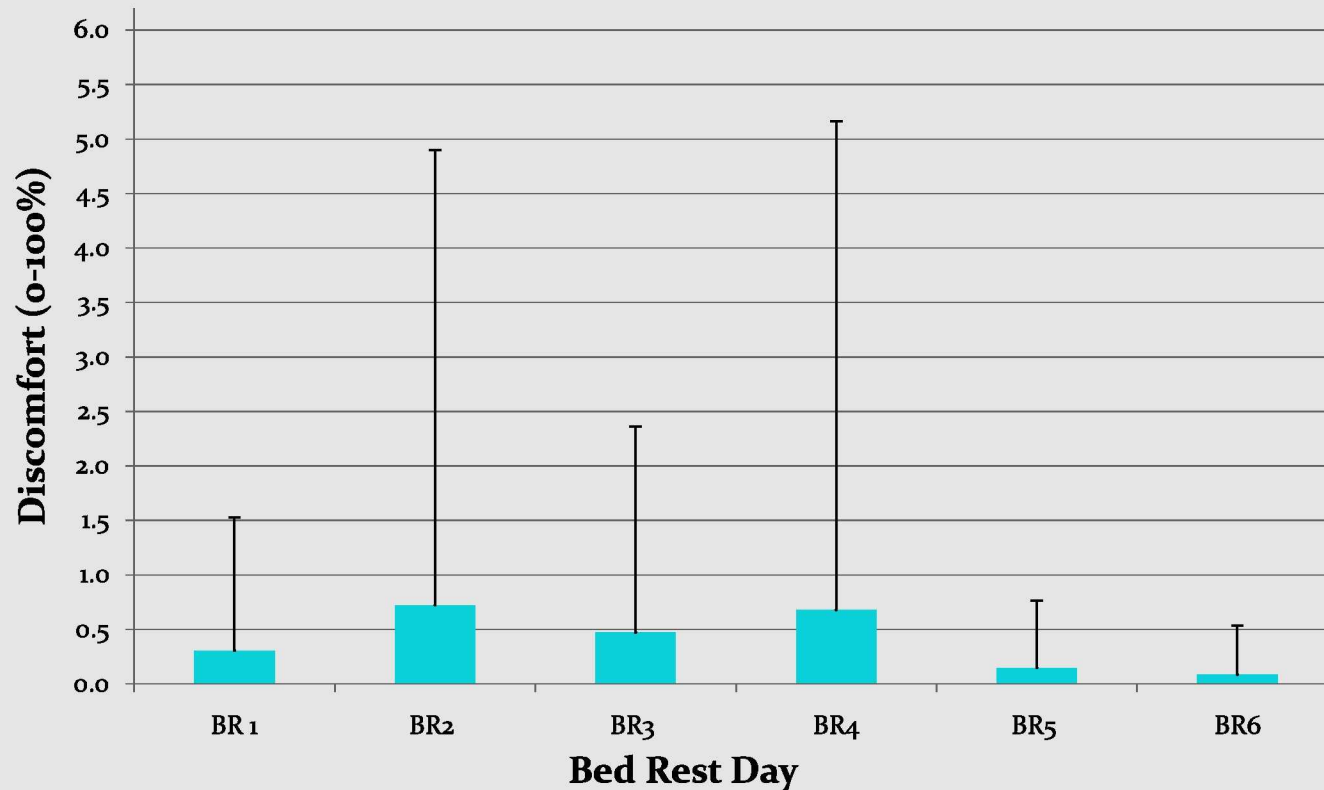
Data for Overall comfort assessment plotted against bed rest days. Data represent means and standard deviations for all subjects on each bed rest day. Discomfort is expressed as zero to 100%. Note the much reduced values as compared to LAFS phase I subjects.

## Lower Back



Data for Lower Back comfort assessment plotted against bed rest days. Data represent means and standard deviations for all subjects on each bed rest day. Discomfort is expressed as zero to 100%. As seen in the overall comfort assessment, values are much reduced as compared to LAFS phase I subjects.

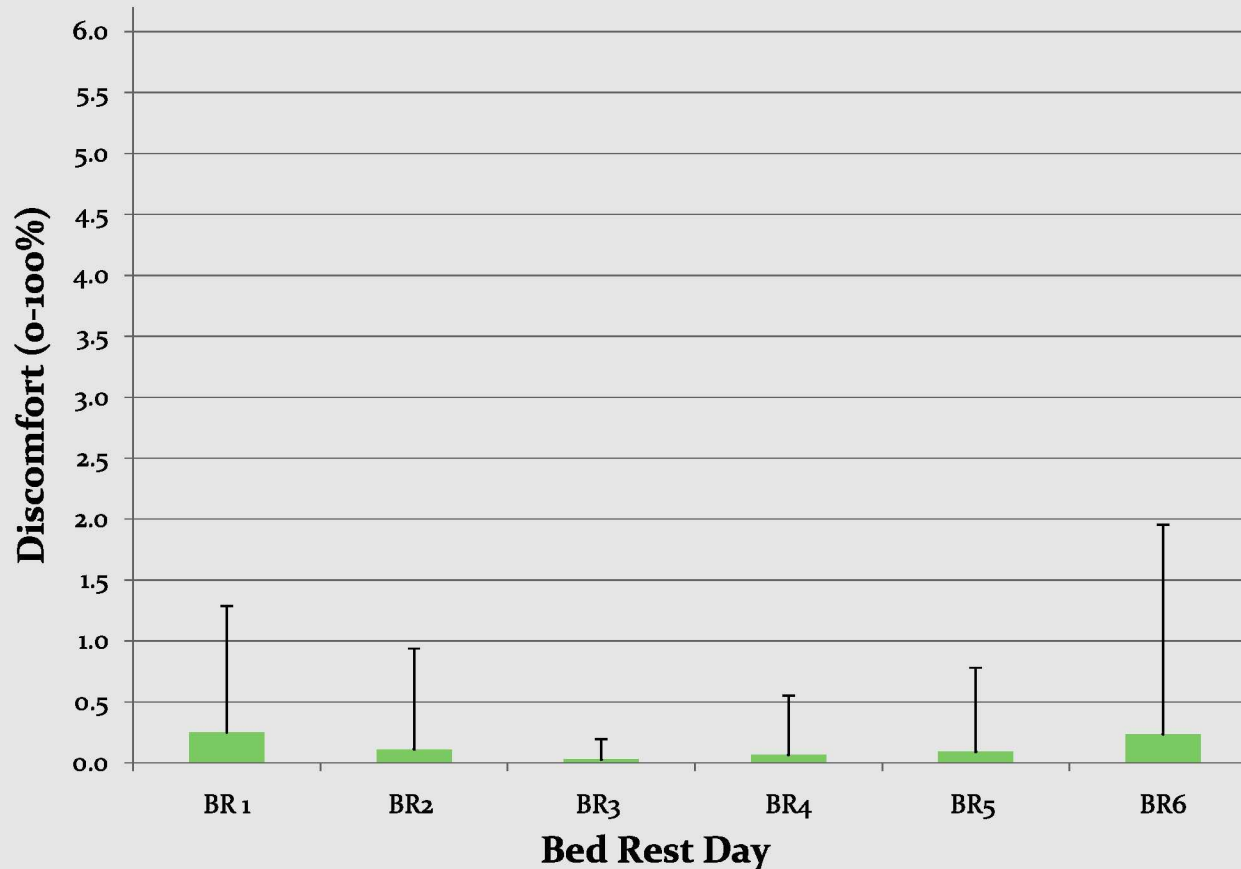
## Feet



Data for the Feet comfort assessment plotted against bed rest days. Data represent means and standard deviations for all subjects on each bed rest day. Discomfort is expressed as zero to 100%. Note that values are markedly reduced as compared to LAFS phase I subjects.



## Knees



Data for the Knees comfort assessment plotted against bed rest days. Data represent means and standard deviations for all subjects on each bed rest day. Discomfort is expressed as zero to 100%. Note the much reduced values as compared to LAFS phase I subjects.

# Force Verification

- 1/6th body weight was verified for each standing position throughout the day.
- Means and standard deviations were calculated across bed rest days for each subject.
- Regression analyses for measured 1/6 body weight against expected 1/6 weight demonstrated  $r^2 = 0.9931$ .



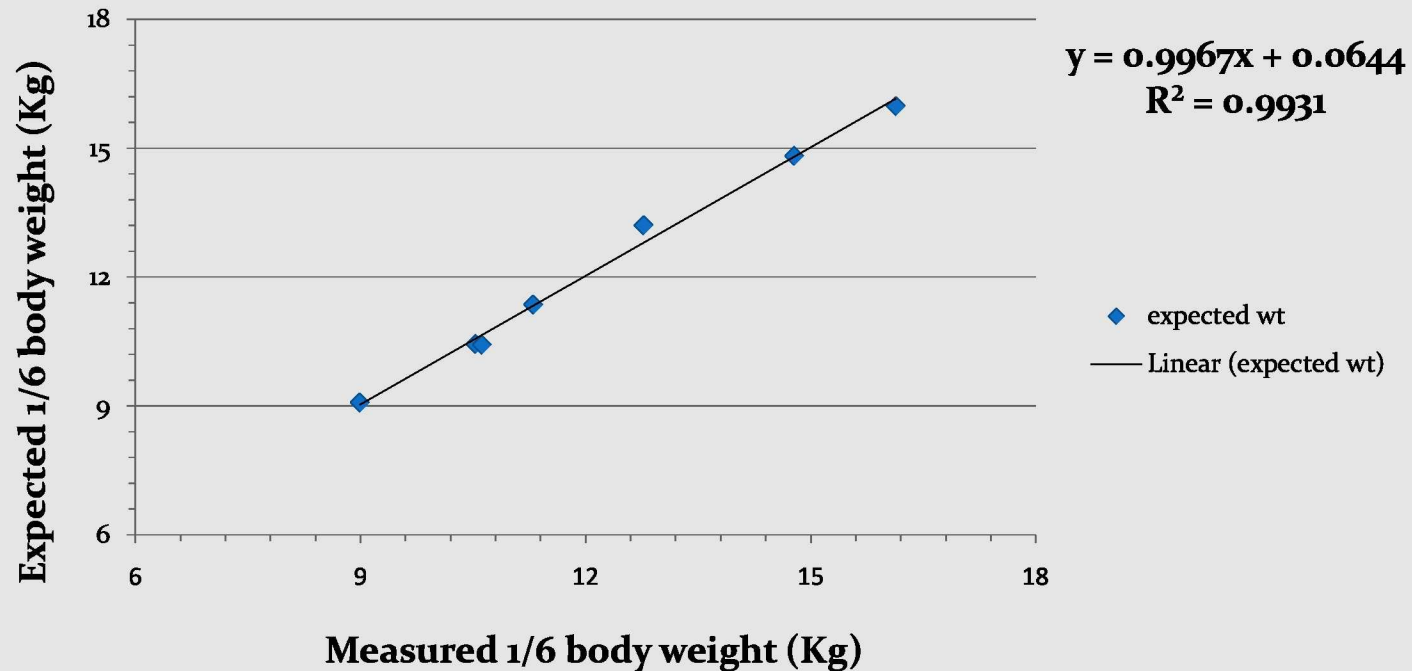
# Force Verification Data

Subject	1 G wt (Kg)	Expected 1/6 wt (Kg)	1/6 wt (Kg)
5107	96.8 ± 0.4	16.0 ± .076	16.1 ± 0.3
6613	89.8 ± 0.2	14.8 ± 0.03	14.8 ± 0.5
8318	80.0 ± 0.3	13.2 ± 0.43	12.7 ± 0.5
8991	63.3 ± 0.6	10.4 ± 0.05	10.5 ± 0.3
5801	63.1 ± 0.5	10.4 ± 0.09	10.6 ± 0.3
5459	68.8 ± 0.5	11.4 ± 0.07	11.3 ± 0.4
6049	55.0 ± 0.4	9.1 ± 0.06	9.0 ± 0.3
Means	73.8 ± 14.3	12.2 ± 2.4	12.2 ± 2.4

Note. Data represent means ± standard deviations.

# Force Verification

## 1/6 Body Weight Verification



This figure depicts the 1/6 force verification during the standing position for LAFS phase II subjects. One sixth of the body weight as measured while “standing” in the bed (x axis) is plotted against the expected 1/6 body weight (y axis) for each subject. Regression analysis indicates 99.3% ( $r^2=0.9931$ ) of the variation in the measured 1/6 body weight is explained by the relationship to the expected 1/6 body weight. In other words, the lunar analog bed accurately imparts a 1/6 load to the subject.

# Plasma Volume

- Plasma volume was assessed in pre bed rest on BR-5.
- Post bed rest testing was completed in the evening on the final day of bed rest, BR6.
- Plasma Volume index was compared pre- and post bed rest.



# Plasma Volume Data

Subject	PVI BR -5	PVI BR6	% change
<b>6613</b>	1.1642	1.1131	-4.394
<b>6380</b>	1.4123	1.2246	-13.291
<b>8318</b>	1.6226	1.6120	-0.654
<b>8991</b>	1.3807	1.3652	-1.124
<b>5170</b>	1.4509	1.2685	-12.570
<b>5801</b>	1.5459	1.2710	-17.787
<b>5459</b>	1.3450	1.2306	-8.508

Plasma volume index for pre-bed rest (BR-5) and post bed rest (BR6) and percent change. Data from one subject was omitted due to equipment malfunction during testing.

# Plasma Volume Results

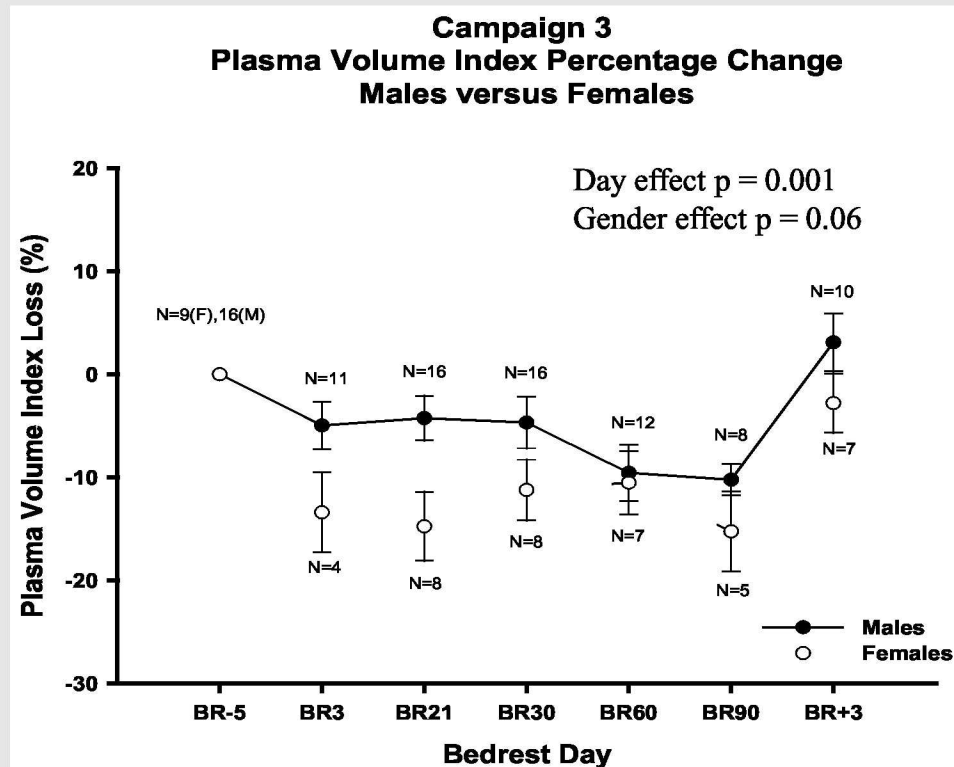
	Plasma Volume Index (PVI)	Confidence Interval
Pre test	$1.42 \pm 0.14$	1.32 – 1.52
Post test	$1.30 \pm 0.05$ *	1.26 – 1.34
Difference	$0.12 \pm 0.09$	0.05 – 0.19
Percent change	$-8.33 \pm 6.1$	-12.85 – -3.81

Notes. Plasma Volume Index data indicate means  $\pm$  standard deviations.

\* indicates significant difference from pretest value ( $p = 0.0098$ ).

Results of the paired t test indicate a significant decrease in plasma volume from pre to post bed rest. Application of lower pressure stockings in combination with foot and ankle movements, reduced PVI to a lesser degree than PVI values observed in LAFS Phase I. This PVI mean is more consistent with the -6% value predicted by Digital Astronaut. Variability of these LAFS Phase II data while large, is less than that observed for the LAFS Phase I data. This may be due in part to the diet stabilization of subjects prior to testing.

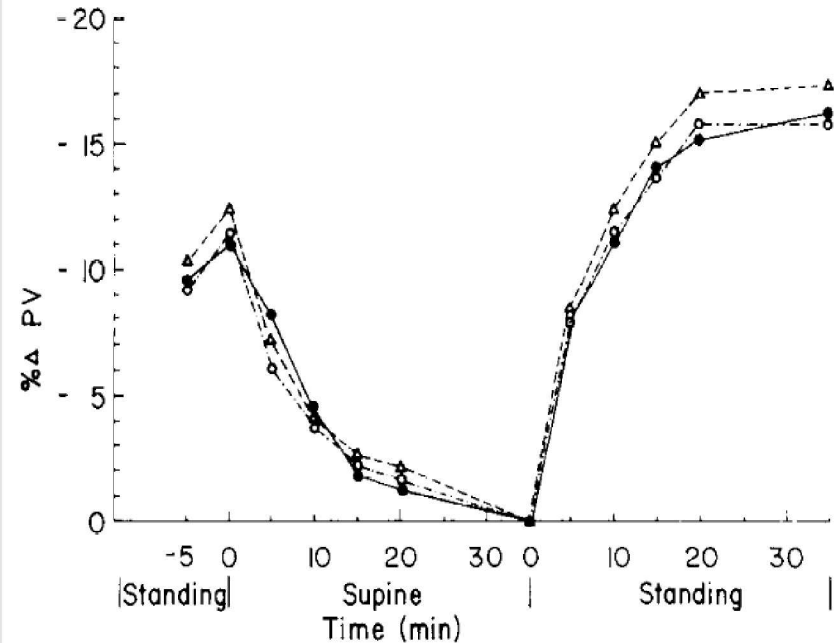
# Plasma Volume Discussion



- Variability observed in the PVI data of LAFS Phase II was not unexpected as it is also seen in 6° head down tilt (HDT) bed rest subjects (see figure above). This graph illustrates the % loss of PVI over long duration HDT bed rest. Data for males and females are plotted to illustrate that females tend to lose PVI to a greater degree than males. This trend toward a male/female difference can account for some of the variability observed in the LAFS Phase II data.

# Plasma Volume Discussion

- The plasma volume response in the lunar analog bed may be accounted for to some degree by changes in posture. In a 1g environment, as a person moves from supine to standing, plasma volume decreases as blood that is redistributed to the extremities creates capillary pressures that are greater than the plasma oncotic pressure. The increased capillary pressure increases the rate of capillary filtration pushing fluid into the interstitial space. This reduces plasma volume and expands the size of the extremities. This process stabilizes within approximately 20 minutes of maintaining the standing position causing a plasma volume reduction of ~16%. Conversely, when a person moves from standing to supine, plasma volume increases. These plasma volume changes are illustrated in the figure at the right.



Percent change in plasma volume (PV) when moving between standing and supine positions. Note the increase in PV in the supine position and subsequent decrease during standing. Figure is from Hagan et al, 1978, J Appl Physiol. Note the descending scale on the ordinate axis. PV is shown calculated by 3 different methods.



# Plasma Volume Discussion

- In this study, subjects slept in the horizontal position and were tilted at  $9.5^{\circ}$  during the day. Therefore, each morning subjects experienced a plasma volume reduction due to the change in posture. Plasma volume then increased when subjects returned to the horizontal position at night. Therefore, subjects were never in one position long enough to allow plasma volume to adapt and stabilize in response to the new body position.
- In contrast during head-down tilt bed rest, subjects are maintained at  $6^{\circ}$  head-down tilt for the duration of the study. As the body adapts to this new position, fluid is redistributed toward the upper body. This accumulation of fluid in the upper body increases central volume and arterial pressure. To reestablish normal arterial pressure, fluid is eliminated thus, reducing plasma volume. This adaptation of decreased plasma volume will remain until the body position changes when the subject gets out of bed. Similarly in spaceflight, astronauts decrease plasma volume as they adapt to the microgravity environment. Once stabilized, changes in body position do not have further effects on plasma volume due to the absence of gravity.